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LEVEL III

AIR FORCE HUMAN RESOURCES LABORATORY

VALIDATION OF AN EXPERT ESTIMATE TECHNIQUE FOR PREDICTING MANPOWER, MAINTENANCE, AND TRAINING REQUIREMENTS FOR PROPOSED AIR FORCE SYSTEMS: APPENDIX A

By

Daniel W. Sauer
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

William B. Askren

ADVANCED SYSTEMS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

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AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DoDD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

GORDON A. ECKSTRAND, Director
Advanced Systems Division

DAN D. FULGHAM, Colonel, USAF
Commander

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18. SUPPLEMENTARY NOTES

This supplement is a prototype guide for implementing the expert estimate method discussed in the basic technical report.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AFSC	maintenance man-hours	subjective estimation
career field	maintenance manpower	task difficulty
crew size	maintenance task time	training facilities/equipment
engineering description package	skill level	training time
expert estimate technique		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives were to determine the validity of an expert estimate technique for predicting manpower, maintenance, and training requirements for equipment in the early stages of design, and to develop a guide for implementing the technique. Sixty Air Force technicians from two avionics AFSCs participated as expert estimators. Twenty of these technicians were also qualified avionics instructors. The 60 technicians made estimates of manpower, maintenance, and training requirements using only an engineering description of an operational avionics component. The description contained information available during the early design stages of the component. The accuracy of the estimates was determined by comparing them with manpower, maintenance, and training data associated with the operational equipment. The results indicate that maintenance task time, crew size, skill level, over

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career field, and task difficulty can be estimated with a satisfactory degree of accuracy. Training times were greatly overestimated. The estimates of required training facilities/equipment and the impact of design features on maintenance were nonconclusive. The results also indicate that ten technicians with skill level 5 and with system experience on equipment similar to the proposed equipment will produce acceptable estimates. A prototype guide for using the technique was prepared.

APPENDIX A

PROTOTYPE USER'S GUIDE FOR COLLECTING EXPERT ESTIMATES OF HUMAN RESOURCES DATA FOR NEW AIR FORCE SYSTEMS

PROTOTPE USER'S GUIDE FOR

COLLECTING EXPERT ESTIMATES OF HUMAN

RESOURCES DATA FOR NEW AIR FORCE SYSTEMS

INTRODUCTION

The Expert Estimation Method

There are several techniques and methods available for predicting the human resource requirements for new Air Force systems. Among these techniques are the historical comparison method, task-analytic method, sovereign factors, modeling techniques and expert estimate techniques. The first four methods require vast amounts of data, complex machine processing or the construction of sophisticated models to produce the human resource estimates. The expert estimate approach requires relatively little in terms of external support and therefore represents a relatively low cost method for producing human resource estimates. The data base for the expert estimate approach is made up of the years of systems experience accumulated by Air Force technicians. It is this data base that the expert estimate technique can rapidly query with small investments of resources.

The expert estimate technique consists of five basic steps. First, an engineering description package is compiled for the equipment or system under study. This description is based on the engineering data and specifications available during the early phases of system design.

Second, a questionnaire is designed to collect the specific human resource estimates desired. The third step is to select the appropriate kinds and quantities of technicians to serve as expert estimators. The fourth step is to take the engineering description package and the questionnaire to the selected experts to collect the desired estimates. The fifth step is to analyze the data. These then are the basic steps involved in using the expert estimate techniques. Each of these steps will be discussed in more detail in separate sections of this guide.

Capabilities/Limitations of the Expert Estimate Method

Recent research[1,2] on the expert estimate method has been directed toward determining the accuracy and reliability of the technique for different types of human resource data. The research has shown that the method can produce accurate and reliable estimates of:

- Maintenance Man-hours
- Crew Size
- Skill Level
- Career Field/AFSC
- Task Difficulty

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[1] Sauer and Askren, Validation of expert estimate techniques for predicting manpower, maintenance and training requirements for proposed Air Force systems. AFHRL-TR-78 - 19 , Wright-Patterson AFB, Ohio. Advanced Systems Division, Air Force Human Resources Laboratory, May 1978.

[2] Whalen and Askren, Impact of design trade studies on system human resources. AFHRL-TR-74-89, Wright-Patterson AFB, Ohio. Advanced Systems Division, Air Force Human Resources Laboratory, December 1974.

The method can also be used to collect technician responses on design features which may present safety hazards or impede efficient maintenance and programs to identify the types of maintenance training facilities and equipment required by a new system. To date, the expert estimate method has not produced satisfactory estimates of maintenance training times for a proposed system.

Applications for the Expert Estimate Method

The expert estimate approach to predicting human resources for new systems does not depend on the availability of prototype or actual system equipment. Estimates can be made with only an engineering description of the proposed system. For this reason the expert estimate approach is ideal for use in the early design stages of new systems before prototypes are constructed. The impact of the system design on the human resources can be assessed and, if necessary, the design can be modified. Since system changes in the early design stages can be effected more easily and are less costly than similar changes made later in the system development process, the expert estimate method can play a significant role in the process of optimizing system cost and system performance.

The expert estimate method could also be used to compare the human resource impacts of two or more alternative designs or engineering solutions. Another application could be in projecting personnel costs and personnel needs for new systems. It could also be used to assist career

field planners. The method could be used as a means of supplementing the data base for more sophisticated human resource estimation techniques or estimation models. It may, after additional research, also be suitable for use in estimating the training needs for new systems.

USING THE EXPERT ESTIMATE METHOD

This section will discuss the steps necessary to prepare for and use the expert estimate method. The approach used is to first present a general description of the step then to give a sample of material relevant to the step.

Developing the Engineering Description Package. This is the first step in preparing for use of the expert estimate method. The engineering description package will contain the only information on the proposed system or equipment that the technician will have. As such, it is critical that as much pertinent information as possible be presented in the package. Generally the engineering description package should contain information on the following:

- Type of Aircraft
- Location of Components on Aircraft
- Physical Description of Components -- Size and Weight
- Functional Description of Components
- Description of Built-in Test Capability
- Description of Test Equipment
- Maintainability

It is possible that many of the details would not be known or would not have been decided during the early design stages. Build the engineering description package from the data that is available. One example of an engineering description package can be found in the 1974 Whalen and Askren[3] report. The engineering description package used in the Sauer and Askren[4] study (1978) is presented on page 63.

There is no set format for the engineering description package. Experience has shown that schematics, block diagrams, flow diagrams, drawings and other graphic aids were very helpful to the technicians who have used the packages. Technicians state that the use of illustrations and diagrams should be about the same or increased relative to the number of illustrations contained in the engineering descriptive package presented below. The length of the engineering package described below is 10 pages (one side) of text and diagrams. Only a small percentage of the technicians stated that this was too long. Most recommended that the length was about right and some stated that it could have been longer.

The main cost of developing an engineering package will be the engineering time necessary to collect, edit and compile the data in a single document. Approximately 120 man-hours of engineering time was required to develop the Engineering Description Package included below. An additional 20 to 30 man-hours of technical drafting, technical

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[3]Whalen and Askren, Op. cit., p. 57

[4]Sauer and Askren, Op. cit., p. 57

typing and technical editing were required. Costs for other packages will depend on the scope of the particular system or component and the availability of the required data.

Example Of An Engineering
Description Package

DOPPLER SIGNAL PROCESSOR
ENGINEERING DESCRIPTION PACKAGE

INTRODUCTION

The Doppler Signal Processor (DSP) unit is designed for operation in conjunction with a Four-Beam Janus, FM/CW Doppler Radar Navigation System to provide continuous direct reading indications of aircraft groundspeed and drift angle.

In order to provide an understanding of the function and operation of the Doppler Signal Processor, it is necessary to briefly outline the overall operation of the Doppler Radar Navigation System.

Four-Beam Janus System

The four-beam "janus" system derives its name from an ancient Roman god who was represented with two opposite faces. The antenna system employs one transmitted beam directed forward, and one transmitted beam directed backward. The reflected signals are sampled by the receiving antenna alternately from

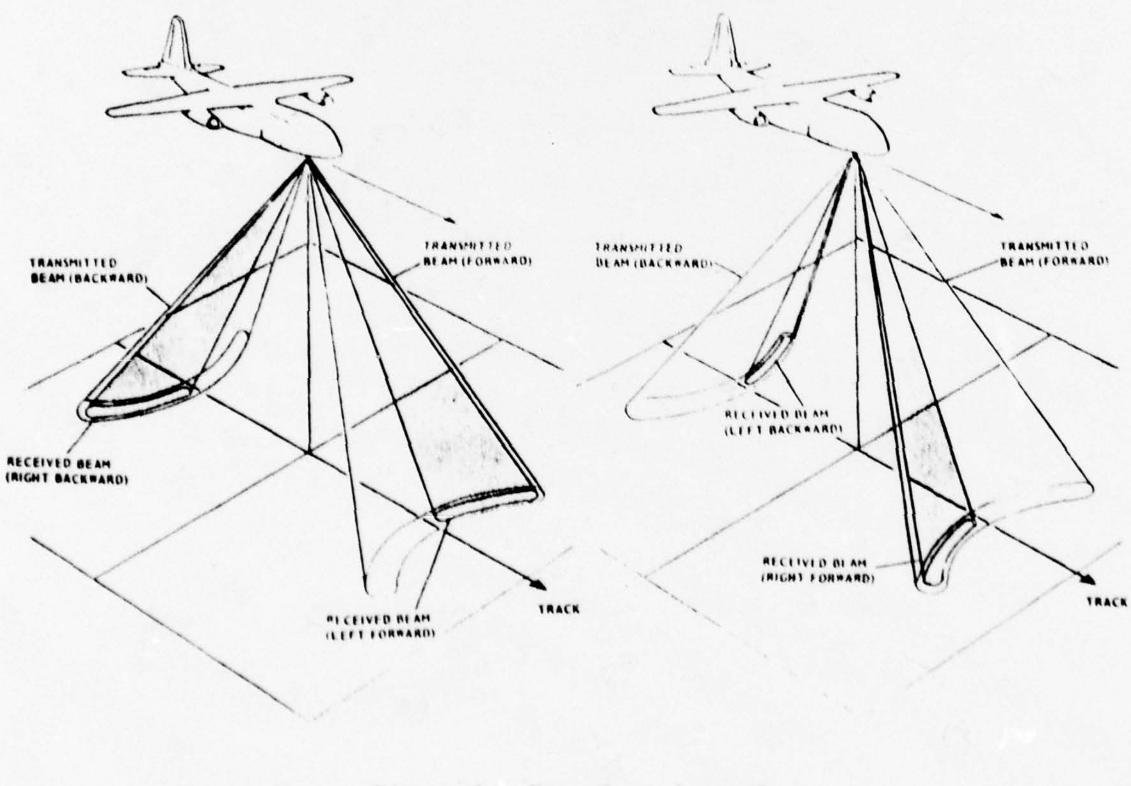

Figure 1. Four-Beam Janus System

the right-front and the left-aft sides of the aircraft, and from the left-front and the right-aft sides of the aircraft. A representation of the four-beam janus system is provided in Figure 1.

Doppler Navigation

Doppler navigation utilizes the doppler effect which is a change in the observed frequency of a wave train, due to relative motion between the frequency source and the receiver. The observed frequency is higher than the source frequency when the distance between the source and the receiver is decreasing. Conversely, when the distance is increasing, the observed frequency is lower than the source frequency. The shift from true frequency depends on the speed and angle of movement of the source relative to the receiver and is defined as doppler shift.

Doppler Radar Navigation System (DRNS)

Groundspeed Measurement - With reference to Figure 1, movement of the aircraft with a forward velocity causes a doppler shift in the received signal frequencies from the forward and aft beams. The combined doppler shift of the right-front (F_{RF}) and left-aft (F_{LA}), or left-front (F_{LF}) and right-aft (F_{RA}) beams is directly proportional to aircraft horizontal groundspeed. By combining the doppler shift from both, the forward and aft beams, inaccuracies due to aircraft pitch or vertical velocity are eliminated.

Drift Angle Measurement - Drift angle information is obtained by comparing the doppler shift F_1 ($F_1 = F_{RF} + F_{LA}$) with the doppler shift F_2 ($F_2 = F_{LF} + F_{RA}$).

When the antenna is aligned with the aircraft direction of motion (Figure 2a), F_1 will equal F_2 and no drift error will be generated. The angle between aircraft heading and aircraft direction of motion is the drift angle. In Figure 2b, the doppler shift F_1 is greater than the doppler shift F_2. The difference between doppler shifts F_1 and F_2 is sensed by the Doppler Signal Processor unit which rotates the antenna to align the beams about the aircraft direction of motion (Figure 2c). This action equalizes the doppler shifts ($F_1 = F_2$) and provides a true drift angle measurement. In Figure 2d, the heading of the aircraft has been altered to compensate for the drift.

System Description - Figure 3 shows a block diagram of the Doppler Radar Navigation System. The transmitter portion of the receiver/transmitter generates a frequency modulated, cw, radio frequency signal which is coupled to the antenna and transmitted in the forward and aft beams. Ground reflected signals are received by the antenna, alternately for 0.75 second periods from the right-front, left-aft and left-front, right-aft beams. A mixer in the antenna unit mixes the received signals with a sample of the transmitted frequency and outputs intermediate frequencies from the left (side A) and right (side B) beams. These signals are demodulated in the receiver portion of the receiver/transmitter and mixed in a manner that only the audio doppler shift frequencies appear at the input to the Doppler Signal Processor unit. (The doppler shift frequency is actually a spectrum of frequencies with the doppler shift represented by the center frequency.) The Doppler Signal Processor combines and processes the doppler audio signals and generates a

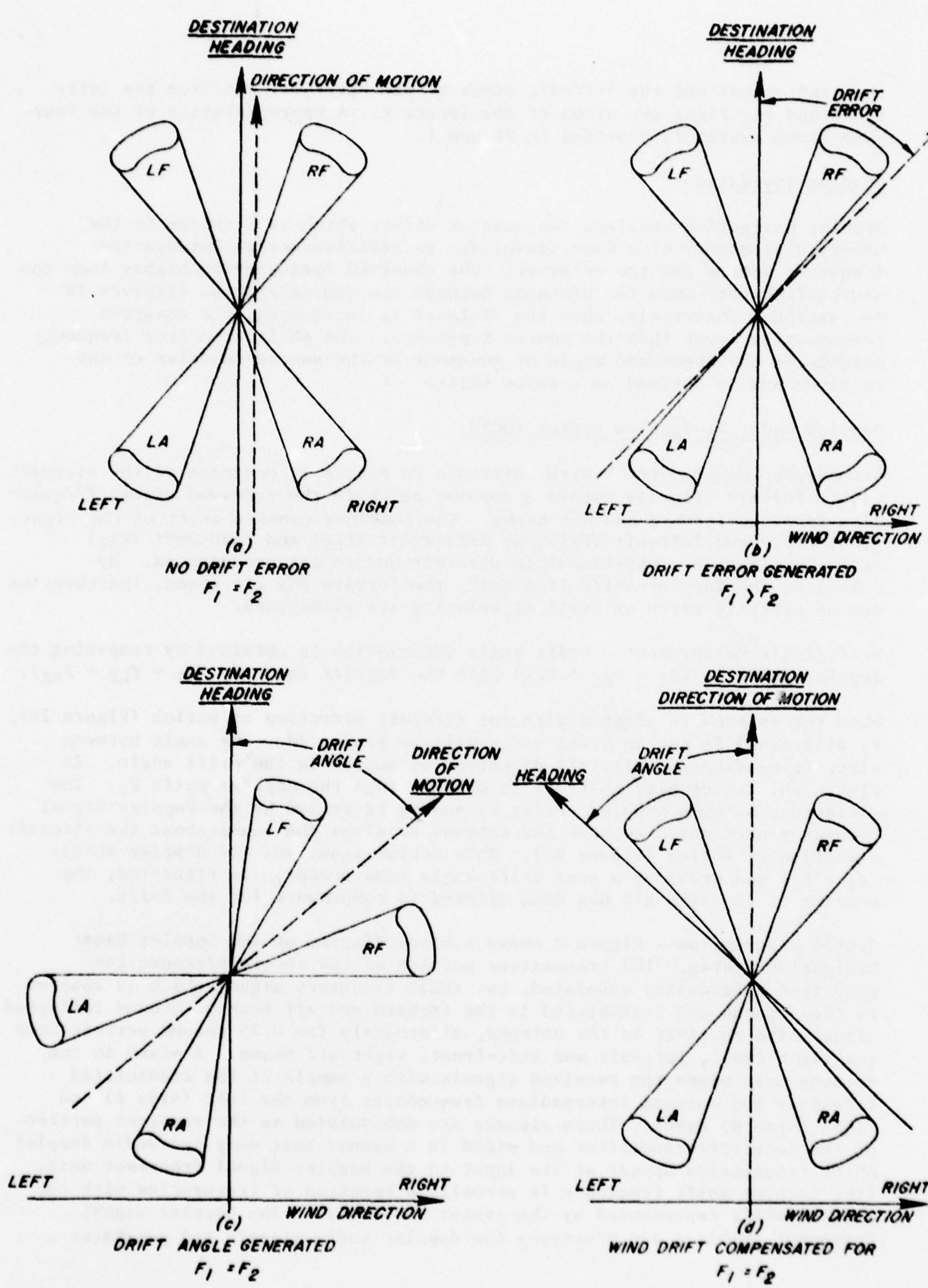

Figure 2. Four-Beam Drift Error Detection

groundspeed analog synchro voltage for driving the groundspeed indicator in the control/indicator panel. The processor also generates a drift error signal for rotating and aligning the antenna with the aircraft direction of motion. A drift angle analog synchro voltage is generated directly by antenna position to provide a drift angle indication on the control/indicator panel. In addition to providing indications of groundspeed and drift angle, the control/indicator panel permits slewing of groundspeed and antenna rotation for test purposes and the selection of Land, High Sea or Low Sea modes of operation for the Doppler Radar Navigation System.

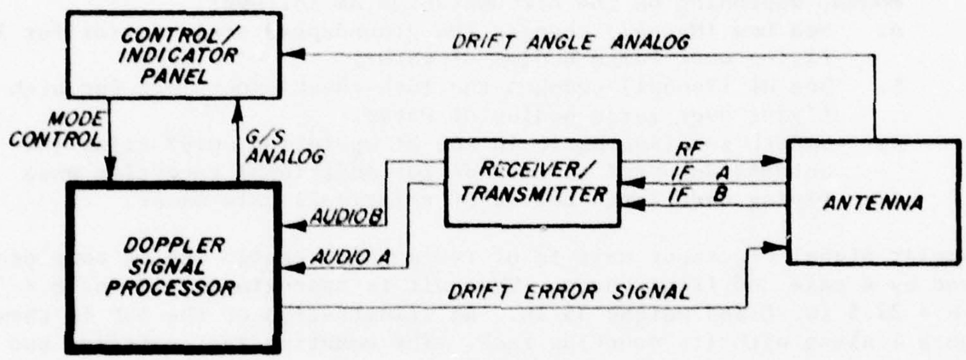

Figure 3. Block Diagram - Doppler Radar Navigation System (DRNS)

DOPPLER SIGNAL PROCESSOR EQUIPMENT DESCRIPTION

General

The purpose of the Doppler Signal Processor (DSP) unit is to convert input doppler frequencies (audio) received from the receiver/transmitter unit into an accurate synchro analog voltage of ground speed, and to monitor the antenna track as compared to the aircraft direction of motion, producing an error signal (drift error) where the two fail to coincide. This error signal is used to align the antenna with the aircraft direction of motion. In addition to these primary functions, the DSP unit has the following secondary functions and capabilities.

1. Groundspeed and Drift manual slew mode, during which time the groundspeed and drift servoloops may be manually slewed to check circuit operation.

2. Lock-check operation, which continuously monitors the strength of the received input signal, the antenna rotor switching sequence, and the ability of the groundspeed and drift circuitry to track the received input signal.

The lock-check operation is accomplished by introducing symmetrical errors to the Doppler Signal Processor and checking the response to these errors. Since the errors are of equal magnitude and of opposite polarity, the overall effect on the accuracy of the DSP is not affected.

3. Memory operation, which freezes the groundspeed and drift circuitry at their last valid outputs should the lock-check circuitry detect a failure.

4. Sea Operation, which is capable of being switched to three different modes, depending on the circumstances as follows:
   a. Sea Low (Manual) changes the groundspeed scale factor for low flying over large bodies of water.
   b. Sea Hi (Manual) changes the lock-check excursions for high flying over large bodies of water.
   c. Smooth sea (Automatic in sea hi operation only) tilts the antenna downward to provide for additional reception when flying over large bodies of relatively calm water.

The Doppler Signal Processor unit is of rectangular design and is completely enclosed by a case and front cover. The unit is approximately 8 in. H × 8 in. W × 22.5 in. L and weighs 35 lb. An illustration of the DSP is shown in Figure 4 along with its mounting rack. The mounting rack contains two connectors for interfacing the DSP with other units in the Doppler Radar Navigation System and two blower motors to provide cooling air to the Doppler Signal Processor.

The DSP is densely packaged and includes a chassis with seven replaceable plug-in modules. The modules contain all active circuitry within the DSP. Following is a list of all modules in the Doppler Signal Processor unit.

1. Test Panel Module (TPM)
2. Audio Processor Module (APM)
3. Signal Comparator Module (SCM)
4. Sequencer Module (SM)
5. Servo Control Amplifier Module (SCAM)
6. Analog Synchro Converter Module (ASCM)
7. Power Supply Module

Vacuum tube circuitry is used throughout the Doppler Signal Processor with the exception of the oscillators located in the sequencer module which incorporate transistor circuits. A brief description of each of the modules is provided in the following paragraphs. A simplified block diagram of the DSP is provided in Figure 5.

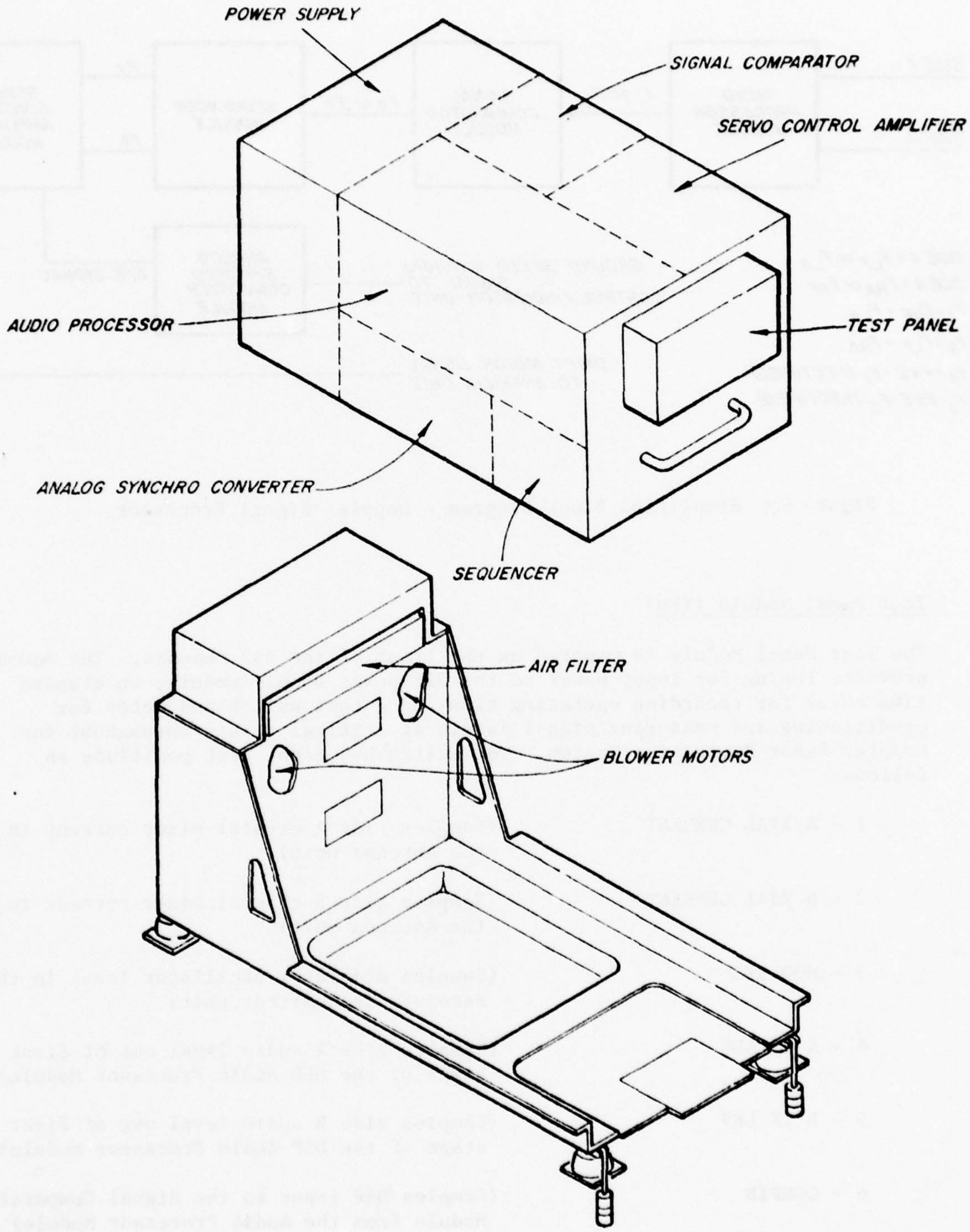

Figure 4. Illustration of Doppler Signal Processor and Mounting Rack Showing Module Locations

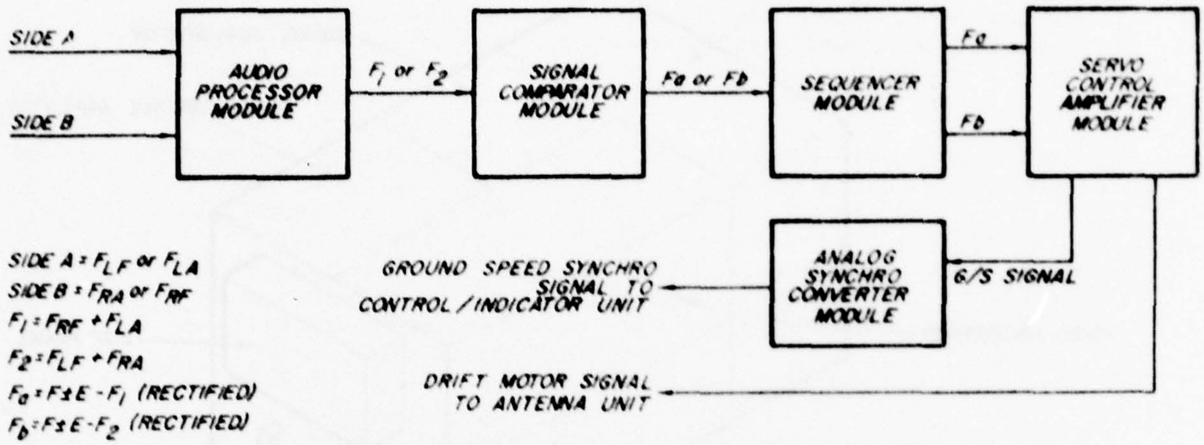

Figure 5. Simplified Block Diagram - Doppler Signal Processor

Test Panel Module (TPM)

The Test Panel Module is mounted on the front of the DSP chassis. The module provides fusing for input power to the DSP power supply module, an elapsed time meter for recording operating time and a test switch and meter for conditioning and measuring signal levels at critical points throughout the Doppler Radar Navigation System. The switch has eight test positions as follows:

1 - A XTAL CURRENT	(Samples side A crystal mixer current in the Antenna unit)
2 - B XTAL CURRENT	(Samples side B crystal mixer current in the Antenna unit)
3 - MOD OSC	(Samples modulator oscillator level in the Receiver-Transmitter unit)
4 - A IF LEV	(Samples side A audio level out of first stage of the DSP Audio Processor Module)
5 - B IF LEV	(Samples side B audio level out of first stage of the DSP Audio Processor Module)
6 - COMPIN	(Samples DSP input to the Signal Comparator Module from the Audio Processor Module)
7 - CALIBRATE	(Used for system calibration)
8 - OPERATE	(Used for normal system operation)

Audio Processor Module (APM)

The function of the Audio Processor Module is to receive detected audio doppler frequency spectra signal pairs, F_{RF}, F_{LA} and F_{LF}, F_{RA} alternately from the receiver/transmitter unit of the DRNS, add the signals in each pair and output the combined frequencies F_1,F_2 alternately for periods of 0.75 seconds each ($F_1 = F_{RF} + F_{LA}$, $F_2 = F_{LF} + F_{RA}$).

The module has two identical channels for processing the incoming signals which include an amplifier, phase splitter, balanced modulator, filter, rectifier and AGC amplifier. AGC voltages are fed back to the first stage amplifier and to the IF amplifier stage in the receiver/transmitter unit of the DRNS.

A third channel in the APM performs the addition of the signals received in each pair and includes three crystals individually selectable by a speed switch located in the Analog Synchro Converter Module, an oscillator, frequency doubler, 3 filters, balanced modulator, square law detector and output amplifier. This channel provides the combined doppler frequency signal output (F_1,F_2) to the Signal Comparator Module of the DSP.

Signal Comparator Module (SCM)

Signals F_1 and F_2 appearing at the output of the Audio Processor Module are actually a spectrum of frequencies *centered about* F_1 or F_2. It is the function of the Signal Comparator Module to determine the exact value of F_1 and F_2. This is accomplished in the SCM by mixing F_1 or F_2 with an accurately controlled frequency ($F \pm E$) generated by a highly stabilized phantastron oscillator. (Note: In order to determine whether the doppler shift frequency is above or below the controlled frequency F, the controlled frequency is varied slightly above and below F by an amount E at a 5 Hz rate.) The output of the mixer is then equal to the difference frequency, $F \pm E - F_1$ or $F \pm E - F_2$. The difference frequency is then amplified, filtered and rectified for further processing in the Sequencer Module as F_a or F_b (F_a = rectified $F \pm E - F_1$, F_b = rectified $F \pm E - F_2$).

The Signal Comparator Module also contains a major portion of the circuitry used in performing the lock-check function on the system and for altering the groundspeed scaling factor when flying over wide areas of water at low or high altitudes. This circuitry includes transformer coupling, phase-sensitive and drift-reversing circuits, and switching relays.

Sequencer Module (SM)

The function of the Sequencer Module is to receive the rectified (F_a or F_b) signal from the Signal Comparator Module and switch it in-phase with the sampling of the right-forward, left-aft and left-forward, right-aft received beams. The switched signal is then filtered and provides two outputs (F_a,F_b) for coupling to the Servo Control Amplifier Module and further processing.

The Sequencer Module also generates the 5 Hz timing for varying the phantastron in the SCM by an amount $\pm E$, and timing, blanking and switching signals used in the lock-check circuitry.

Circuitry within the SM includes 4 oscillators, 5 flip-flop circuits, a relay, an electronic switching matrix and 2 filter circuits.

Servo Control Amplifier Module (SCAM)

The function of the Servo Control Amplifier Module is to receive the two signals F_a and F_b from the Sequencer Module and convert them to a groundspeed error signal for driving a motor-generator in the Analog Synchro Converter Module and a 115 Vac drift motor signal for aligning the antenna with the aircraft direction of motion.

The SCAM also contains circuitry that responds to the lock-check signals and provides warning signals to the DRNS control/indicator to signal returned signal unreliability and/or DRNS failure. The Servo Amplifier Control Module circuitry contains a magnetic modulator, amplifier, buffer, drift reversing stage, 2 transformers, 2 phase-sensitive detectors, 2 magnetic amplifiers and 4 relays.

Analog Synchro Converter Module (ASCM)

The primary function of the Analog Synchro Converter Module is to convert the groundspeed error signal received from the servo control Amplifier Module into a three-wire synchro output voltage for driving the groundspeed indicator in the control/indicator unit of the DRNS.

Secondary functions include the switching of oscillator crystals in the Audio Signal Processor Module and control of the phantastron oscillator frequency (F) in the Signal Comparator Module.

The ASCM consists of 2-speed cams with switches, a synchro transmitter and potentiometer, coupled by a common shaft to a motor-generator. The ground speed error signal drives the motor-generator.

Power Supply Module (PSM)

Aircraft input voltage to the Power Supply Module consists of 28 Vdc and 115 Vac / 400 Hz / single-phase via fuses located in the Test Panel Module. The Power Supply Module output voltages include:

6.3 Vac	120 Vdc
18 Vac	280 Vdc
26 Vac	500 Vdc
115 Vac	-150 Vdc
28 Vdc	-425 Vdc

The Power Supply Module contains 2 multi-output transformers, 16 rectifier diodes, 8 regulator tubes and 2 relays.

VACUUM TUBE AND TRANSISTOR COMPLEMENT

The Doppler Signal Processor unit contains 29 vacuum tubes and 4 transistors.

BUILT-IN-TEST

The lock-check circuitry within the Doppler Signal Processor unit provides a continuous and reliable test of the overall Doppler Radar Navigation System performance during normal operation.

The capability for the operator to manually slew the drift and ground speed loops, coupled with the measurement of critical test points on the Doppler Signal Processor unit Test Panel Module, aids in isolating failures to a major unit of the DRNS (i.e., antenna unit, receiver/transmitter, Doppler Signal Processor, etc.).

MAINTAINABILITY

Remedial maintenance at the organizational level consists of replacing the faulty unit.

Periodic and remedial maintenance of the Doppler Signal Processor at the intermediate level is carried out using a hot mock-up approach. In the hot mock-up approach, the Doppler Signal Processor is interfaced with other units of the DRNS to provide a full-up operating system.

Extender cables permit the DSP modules to be operated in a normal manner while removed from the DSP. Additionally, where applicable, they provide for inputs, test probing, and switching of various signals for test purposes.

The hot mock-up approach, in conjunction with standard and special test equipment, provides for fault isolation to the component level within a given module of the Doppler Signal Processor unit.

TEST EQUIPMENT

The following test equipment is required for calibration and fault isolation on the Doppler Signal Processor unit.

1. DC VTVM, John Fluke 803 or equivalent
2. AC VTVM, Hewlett-Packard 400D or equivalent
3. Multimeter, Hewlett-Packard 851B or equivalent
4. Frequency Counter, Hewlett-Packard 5245L or equivalent
5. Audio Signal Generator, Hewlett-Packard 200CD or equivalent

Developing the Questionnaire. The development of the questionnaire is a process of selecting the appropriate question formats for the types of human resource estimates desired. It is recommended that maintenance task scenarios be devised for estimates of maintenance task time, crew size, skill level, and task difficulty. These scenarios describe the type of maintenance action taken and the system or component involved in the action. Maintenance location and type of malfunction can also be added to this scenario. Estimates for different maintenance tasks will require a different scenario. The only limit to the number of task scenarios which can be included will be the number of task time, crew size, skill level, and task difficulty estimates desired. The sample questionnaire on page 76 illustrates the use of maintenance task scenarios.

For estimates of task maintenance time it is recommended that the technicians consider three task times. To help technicians estimate average task times, have them also consider the minimum time and maximum time in which a task could be completed. Do not ask the technicians to estimate man-hours. Man-hours will be calculated during the data analysis phase using crew size estimates. For this reason, crew size estimates must be collected simultaneously with task time estimates.

Crew size estimates can be made in terms of the percentage of times a particular task will require a crew of one, two, three or more technicians. Present the possible crew sizes for a particular task and

have the technicians indicate next to each crew size the percentage of times that size crew would be required to perform the scenario maintenance task. Skill level estimates can be made in conjunction with crew size estimates. Have technicians estimate the skill levels (three, five, seven or nine) for the member(s) of the crew(s) they estimated would be required to perform the task.

Task difficulty estimates can be made for each maintenance task scenario. Technicians rate the difficulty of the maintenance tasks for the proposed equipment on a task difficulty scale (100 mm long) with verbal anchors of "Very Easy" (0 mm), "Average Difficulty" (50 mm) and "Very Difficult" (100 mm) to indicate the direction of the scale. Technicians will consider their past maintenance experience on similar equipment as a basis for rating the difficulty of the maintenance tasks for the proposed equipment.

Career field or AFSC estimates need only be made once. It is recommended that these estimates be made after the technicians have completed the estimates for the various maintenance task scenarios. It is helpful to identify the group of current AFSCs from which technicians would most likely be chosen to maintain the new system. This information can be found in the Airman Classification Regulation, AFR 39-1. A series of questions are recommended to extract as much information from the estimators as possible. First, ask if the maintenance technicians would come from one of the identified AFSCs. If a yes answer is given, have the technicians estimate the specific AFSC of the maintenance technicians. If a no answer is given, have the estimators check one of

four possibilities: a new AFSC, a combination of AFSCs, a new shredout for an existing AFSC or expand the duties of an existing AFSC.

If additional information is desired on the impact of design features on maintenance tasks, an open-ended response format is recommended to allow for a potentially wide range of responses. This format is also appropriate if estimates of training facilities/equipment is desired.

Since accuracy of training times collected by the expert estimate method have thus far proven unsatisfactory it is not recommended that estimates of training times be collected.

The time necessary to develop a questionnaire should range from between 20 to 40 hours depending on the number and type of estimates involved. This would include time for defining the maintenance task scenarios and time for typing and reproduction.

Example of A Questionnaire

EQUIPMENT DESIGN EVALUATION FOR
MAINTENANCE, MANPOWER AND TRAINING REQUIREMENTS

You are participating in a study to determine the feasibility of having experienced Air Force technicians estimate manpower and training requirements for new Air Force equipment. You will estimate maintenance crew sizes, maintenance task times, skill levels, task difficulty, career field and training requirements for a piece of equipment called the doppler signal processor.

Your estimates of manpower and training requirements for the doppler signal processor will be based on information contained in the engineering description package prepared for the doppler signal processor. The information in this package is typical of the information available during the early stages of equipment design. Please read the entire equipment description before making your estimates. Note that you may refer to the engineering description package as often as you wish while making your estimates.

The equipment design evaluation questionnaire is divided into four sections: Maintenance Manpower Requirements, Maintenance Training Requirements, Background Data and Evaluation of the Engineering Description Package. Please read the instructions carefully before completing each section. Examples will be provided in several cases to illustrate the proper response technique. Since there is no time limit, please consider each question and response carefully. You may ask questions at any time while completing this questionnaire.

MAINTENANCE MANPOWER REQUIREMENTS

In this section of the equipment design evaluation questionnaire, you will estimate task time, crew size, crew skill level, task difficulty, and the probability of making an error for each of 6 maintenance tasks. Each maintenance task will be described in terms of four aspects; equipment name, type of malfunction, maintenance action taken, and maintenance location. Please refer to the engineering description package as often as necessary while making your estimates.

After you have estimated the manpower data items for the maintenance tasks, you will be asked to estimate the most appropriate career field for technicians maintaining the doppler signal processor.

MAINTENANCE TASK 1

Equipment Name: Doppler Signal Processor (DSP)

Type Malfunction: No Output

Maintenance Locations: Flight Line

Maintenance Action Taken: Remove and Replace

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

		Skill Level(s)			
1 Technician	____	____			
2 Technicians	____	____	____		
3 Technicians	____	____	____	____	
4 Technicians	____	____	____	____	____
	100				

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ____________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ____________________
(hours and minutes)

Maximum Completion Time ____________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 1

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult		Average Difficulty		Very Easy

MAINTENANCE TASK 2

Equipment Name: DSP

Type Malfunction: Lock on Malfunction

Maintenance Locations: Flight Line

Maintenance Action Taken: Remove

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

		Skill Level(s)			
1 Technician	______	____			
2 Technicians	______	____	____		
3 Technicians	______	____	____	____	
4 Technicians	______	____	____	____	____
	100				

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ______________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ______________________
(hours and minutes)

Maximum Completion Time ______________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 2

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult	Average Difficulty	Very Easy

MAINTENANCE TASK 3

Equipment Name: DSP

Type Malfunction: Lock on Malfunction

Maintenance Locations: Flight Line

Maintenance Action Taken: Adjust

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

		Skill Level(s)			
1 Technician	______	____			
2 Technicians	______	____	____		
3 Technicians	______	____	____	____	
4 Technicians	______	____	____	____	____
	100				

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ______________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ______________________
(hours and minutes)

Maximum Completion Time ______________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 3

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult		Average Difficulty		Very Easy

MAINTENANCE TASK 4

Equipment Name: DSP

Type Malfunction: Lock on Malfunction

Maintenance Locations: Shop

Maintenance Action Taken: Repair

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

Skill Level(s)

1 Technician ______ ____

2 Technicians ______ ____ ____

3 Technicians ______ ____ ____ ____

4 Technicians ______ ____ ____ ____ ____

100

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ______________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ______________________
(hours and minutes)

Maximum Completion Time ______________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 4

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult		Average Difficulty		Very Easy

MAINTENANCE TASK 5

Equipment Name: Power Supply Module

Type Malfunction: No Output

Maintenance Locations: Shop

Maintenance Action Taken: Bench Check - Repair Deferred

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

		Skill Level(s)			
1 Technician	______	____			
2 Technicians	______	____	____		
3 Technicians	______	____	____	____	
4 Technicians	______	____	____	____	____
	100				

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ______________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ______________________
(hours and minutes)

Maximum Completion Time ______________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 5

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult		Average Difficulty		Very Easy

MAINTENANCE TASK 6

Equipment Name: Signal Comparator Module

Type Malfunction: Lock on Malfunction

Maintenance Locations: Shop

Maintenance Action Taken: Repair

Crew Size and Skill Level

Listed below are the possible crew sizes to perform the above maintenance action. For 100 times that this maintenance action is performed, how many times would the crew size be.

		Skill Level(s)			
1 Technician	________	____			
2 Technicians	________	____	____		
3 Technicians	________	____	____	____	
4 Technicians	________	____	____	____	____
	100				

Maintenance Action Time

Please estimate the amount of time to complete the above maintenance action under normal circumstances. This would be your estimate of an average completion time.

Average Completion Time ________________________
(hours and minutes)

Now estimate maintenance action completion times for extremely favorable circumstances (minimum task completion time) and for extremely unfavorable circumstances (maximum task completion time)

Minimum Completion Time ________________________
(hours and minutes)

Maximum Completion Time ________________________
(hours and minutes)

*DO NOT ESTIMATE MAN-HOURS. THIS WILL BE COMPUTED BY MULTIPLYING YOUR TIME ESTIMATES BY YOUR CREW SIZE ESTIMATE.

TASK 6

Maintenance Action Difficulty

Please place an X on the rating scale below to indicate how difficult you think this maintenance action would be. Rate the difficulty in comparison with avionics maintenance actions you are familiar with.

Very Difficult	Average Difficulty	Very Easy

Career Field

It is assumed that maintenance technicians for this equipment will come from the 328XX Career Field. Would the maintenance actions associated with this design require any changes to the AFSC's within the 328XX Career Field? YES ________ NO ________

If you answered YES, which of the following changes do you think would be appropriate?

________ A new AFSC (career ladder)

________ A combination of AFSC's (career ladders)

________ A new shredout for an existing AFSC (career ladder)

________ Expand duties of an existing AFSC (career ladder)

Career Field

Which Air Force Specialty listed below would be most likely to perform the preceding 6 maintenance actions?

_____________ 328X0 - Specialty Summary - Installs, maintains, modifies, troubleshoots, and repairs avionic communications equipment and test equipment.

_____________ 328X1 - Specialty Summary - Installs, maintains, troubleshoots, and repairs avionic electronic navigation systems equipment and test equipment.

_____________ 328X2 - Specialty Summary - Inspects, repairs, overhauls, modifies, and maintains airborne early warning radar systems and test equipment.

_____________ 328X3 - Specialty Summary - Installs, maintains, and repairs avionic electronic warfare equipment, ground electronic intercept and analysis equipment, and special purpose test equipment.

_____________ 328X4 - Specialty Summary - Installs, maintains, and repairs avionic inertial and radar navigation equipment and test equipment.

_____________ Other AFSC

Task Difficulty, Safety, Errors and Time

Please identify any design features of the doppler signal processor you feel would make maintenance particularly difficult.

Please identify any design features which could present safety hazards.

Please identify any design features which could increase maintenance time.

Please identify any design features which could contribute to maintenance errors.

TRAINING REQUIREMENTS

In this section of the expert opinion questionnaire, you will be requested to estimate training time, training type, training content, and special training facilities or equipment needed for maintenance on the Doppler Signal Processor (DSP). You will be asked to make these estimates for airmen with no avionics experience and for airmen with avionics experience.

When making your estimates assume that the inexperienced person is in his first enlistment, has just completed basic training, and is ready and qualified for technical training. Assume that the experienced person is currently a 5-level avionics technician. Your task is to specify the amount of training which will be required to qualify these individuals to perform at a 5-level on the DSP.

Training Requirements

The table below presents general training topics for three types of Air Force training. Your task is to estimate the number of hours of training for each topic within each type of training which would be necessary to bring both inexperienced and experienced individuals to 5-level proficiency on the DSP. If you feel that a topic should not be covered indicated this with a zero in the appropriate blank. You may refer to the engineering description package as often as necessary while making your estimates.

Training Topics	Types of Training		
	Resident (Inexperienced)	OJT (Inexperienced)	FTD (Experienced)
Basic Electronics	______	______	______
Equipment Orientation (Doppler Signal Processor)	______	______	______
Theory of Operation (Doppler Signal Processor	______	______	______
Maintenance (Doppler Signal Processor)	______	______	______
______ (Other)	______	______	______

*40 hours = 1 week

Listed below are topics included in the general category of maintenance training. Please estimate the amount of maintenance training time which should be devoted to each of these topics. Base these estimates on the number of hours you estimated above for maintenance within each type of training.

For example, if you estimated that 100 hours of resident training should be devoted to maintenance, your task would be to estimate how these 100 hours should be distributed over the specific maintenance topics listed below. Follow the same procedure for OJT and FTD training. Indicate zero if you feel a particular topic should not be covered. The values in each type of training column should equal the number of maintenance training hours estimated above for that type of training.

Maintenance Training	Resident (Inexperienced)	OJT (Inexperienced)	FTD (Experienced)
Remove	________	________	________
Replace/Install	________	________	________
Bench Check	________	________	________
Repair	________	________	________
Calibrate	________	________	________
Adjust	________	________	________
Test/Inspect/Service	________	________	________
Check	________	________	________
Assemble	________	________	________
Disassemble	________	________	________
Total Hours	________	________	________

(Use number of hours *estimated for maintenance* under each type of training)

Training Facilities/Equipment

What types of training devices, training equipment, and training aids would be required to support the following training topics:

Basic Electronics ____________________

Equipment Orientation ____________________

Theory of Operation ____________________

Maintenance ____________________

____________ ____________________

(Other)

BACKGROUND DATA

RANK____ AFSC____________________

Career Field Experience Years_______Months__________

Systems Experience

(list current system first)

System	Months of Experience

Training History

Course Name	Length of Course

Select Expert Estimators

Expert estimators should be selected primarily on the basis of their systems experience. Research has shown that it is desirable to select as estimators maintenance technicians with experience on equipment or systems similar to the proposed equipment or system. Because of the variety of new systems under development it is impossible to give any more specific advice on the ideal equipment or systems experience necessary.

Once the initial group has been identified, it is possible to select specific raters. In terms of skill level, research on expert estimators has not included three-level technicians. Therefore, it is recommended that at least five-level technicians be selected as estimators. Research has also shown no differences in the accuracy of estimates for groups differing in length of system experience.

The minimum recommended quantity of expert estimators is 10. If a greater degree of accuracy is desired and if resources permit, the number of estimators may be increased to 20. Analyses of man-hour estimates from groups of 5, 10, and 20 indicate that the variability in estimates decreases for groups of 10 and 20. There is less of a chance, therefore, of obtaining extremely high or low estimates with the larger groups. The interrater reliability coefficients for groups of 10 expert estimators range from .77 to .79 while the coefficients for groups of 20 expert estimators range from .87 to .88.

Data Collection

The data collection could be accomplished in two ways. Maintenance technicians could be brought to the engineering office responsible for the analysis of the proposed equipment or data collection visits could be made to the maintenance technicians at their home base. Experience to date is with data collection visits to the Air Force bases.

Arrangements should be made to conduct data collection visits to the bases where the selected estimators are assigned. Data collection sessions may need to be scheduled around the technicians' duty hours and could be scheduled during any of the work shifts. Data collection sessions can be conducted with technicians individually or in group settings of from two to 20 technicians. This would depend, of course, on technician availability and availability of a suitably sized room. Each technician should be given a copy of the engineering description package and the questionnaire. A short briefing on the purpose of the data collection should be conducted to motivate the technicians to complete the questionnaires as carefully and accurately as possible. Technicians should be encouraged to refer to the engineering description package as often as necessary during the session. Although the questionnaire is not a test, individual answers rather than a group consensus are required.

The cost and time involved in the data collection phase are affected by the geographical location of the base, the number of individuals sent to collect the data and the availability of the selected estimators. As

an example of one aspect of data collection costs, technicians completed the questionnaire presented earlier in from 1.5 to 2.5 hours. The total number of technicians surveyed at each base varied from nine to 20. These group sizes required data collection visits of from 1.5 to 2.5 days duration. These times are based on using one data collector. Additional data collectors can be used to reduce data collection time.

Data Analysis

The data analysis varies in complexity for individual manpower and maintenance data items. The recommended analysis procedure for each item will be discussed in detail in the paragraphs below.

The recommended analysis of the maintenance task time estimates will yield a man-hour estimate for the specified maintenance task. The first step is to calculate the estimated man-hours for each maintenance task. To do this, determine the crew size estimated as most likely to perform the maintenance task. Multiply the task time by crew size to determine man-hours. For example, if the estimated task time is 2.6 hours and the crew size most likely to perform this task is two, the man-hours for this task would be 5.2. Calculate all the man-hours for a given task and determine the mean man-hours value. Research has shown that technicians tend to underestimate task times which then result in underestimates of man-hours. Task time estimates reported by Whalen and Askren (1974) averaged 70 percent of actual task times. This study

found that, on the average, man-hour estimates were 66 percent of actual man-hours expended. Since the latter percentage was based on man-hour estimates it is recommended that this value be used as a correction factor. The correction factor is applied to the mean man-hour estimate for a given task to arrive at a corrected man-hour estimate. The corrected man-hour estimate is determined by dividing the mean estimated man-hours by .66. If, for example, the mean estimated man-hours were 2.47, the corrected man-hour estimate would be 3.74.

The analysis of estimated crew size is somewhat less complex. First, determine the mean percentage of time a particular crew size would be required to perform a given maintenance task. For example, technicians may estimate that for a remove and replace task a two-man crew would be required 75 percent of the time and a three-man crew would be required 25 percent of the time. If the purpose of the survey is to determine only the most likely crew size, then the investigator, using the example above, would report that a two-man crew would be most likely to perform this task.

If it is desired to know how often crew sizes will vary in performance of that task, correction factors must be applied. Research has determined that technicians tend to underestimate the percentage of time a particular crew size is required. Their time estimates are, on the average, 93 percent of the actual values. To obtain corrected values divide the estimated percentage by .93. If it was estimated that a two-man crew was required 75 percent of the time, as in the example above, the corrected percentage would be 80.6.

The analysis of the skill level estimates involves calculating the frequency of responses for each skill level or combination of skill levels in the case of two or more crew members. The skill levels receiving the highest number of responses would represent the predicted skill levels necessary for the particular task.

A similar analysis would be required for determining the predicted career field/AFSC. If the majority of the technicians estimate that one of the current AFSCs represents the appropriate combination of skills and training for the proposed system, then that AFSC is the predicted AFSC for the new system. If this is not the case, then a detailed evaluation of the other responses needs to be made. These responses would indicate whether technicians recommend the creation of a totally new AFSC, a combination of existing AFSCs, the creation of a new shred-out for an existing AFSC or the expansion of duties of an existing AFSC.

Task difficulty estimates are calculated by using a 100mm scale to convert the marks on the difficulty scale to scores. After calculating the mean task difficulty score for a particular task a correction should be applied. Previous research has shown that technicians tend to underestimate the degree of difficulty of maintenance tasks on the proposed system. That is, technicians rated the maintenance tasks on the proposed system as being less difficult than the criteria task difficulty ratings for the same tasks. To obtain a corrected task difficulty estimate, divide the mean task difficulty estimate by .74. For example, if the mean estimated task difficulty score is 35, the corrected score is 47.3.

Using the Expert Estimates

The recommendations presented to this point came as a result of research on the validity and reliability of expert estimates of human resources data for new systems. Little, if any, research has been directed toward defining the ways in which the estimates can be used. Because of this lack of research this prototype guide can only recommend the methods for obtaining accurate and reliable estimates. Although readers are advised to proceed with caution, it seems that there are a number of valid ways in which the estimates can be used. Additional research will be necessary to totally define these applications.